VOLUME VII #6 JULY 1992 PRICE $3.50

FOR THE DESIGN, CONSTRUCTION AND ENJOYMENT OF UNUSUAL SOUND SOURCES

EXPERIMENTAL MUSICAL INSTRUMENTS

IN THIS ISSUE

WINDS, ROCKS, TREES, INSECTS

Leif Brush creates systems for listening to and sometimes modifying the sounds of hidden natural events. The photograph below shows a part of one of his installations, in which wires strung between trees can be monitored for the tiny sounds of natural happenings in their vicinity. This and other *Terrain Instruments* are described in Leif Brush's article in this issue of **Experimental Musical Instruments.** Also in this issue we have Robin Goodfellow's report on rocks — specifically, natural rock whistles created by certain species of rock-boring sea life. We have the second half of an article on winds — being a discussion of acoustic behavior in wind instrument air columns. We have Richard Graham's essay on the process of invention in musical instrument types in the African diaspora. And there's much more. Open and read.

Above: Terrain Instrument: Treeharps Networking,created by Leif Brush See the article starting on page 6. Photo by Gary Morrison.

LETTERS

NOTES FROM HERE AND THERE

THE SOUNDSCAPE NEWSLETTER has recently come into being. The new periodical is devoted to information exchange among people concerned with (in the newsletter's words) "the quality of the contemporary soundscape, the quality of listening, and who are actively addressing issues such as acoustic ecology, acoustic design, noise, silence, music in a 'muzak-ridden' world, and more." The newsletter comes out of the Department of Communication at Simon Fraser University in British Columbia, as part of the World Soundscape Project founded by R. Murray Schafer in the late 1960s. It's edited by Canadian sound artist Hildegard Westerkamp. The cost is Can. $10 in Canada; U.S. $10 elsewhere, from The Soundscape Newsletter, World Soundscape Project, Department of Communication, Simon Fraser University, Burnaby, BC, Canada, V5A 1S6.

EMI'S NEW SCHEDULE, FORMAT, AND PRICING will all go into effect starting next issue (Volume VIII #1). Here's the deal:

Schedule:

Henceforth, **Experimental Musical Instruments** will no longer appear bi-monthly, but will appear quarterly instead. The new issue dates will be the first of September, December, March and June (with each issue actually appearing one month before its cover date).

Format:

With the quarterly schedule, the number of pages per issue will increase so that the total number of pages per year will equal or exceed what it has been. In general, we will abandon our past practice of trying always to squash all the content of each issue into a fixed number of pages, and instead allow the issue size to fluctuate and expand as needed to accommodate the content.

Pricing:

The subscription price will rise to $25 per year for the U.S., U.S. $28 for Canada & Mexico, and U.S. $34 overseas. Back issue and cassette tape prices will rise as well. California residents, due to forces beyond our control, will pay a sales tax. See our ads at the end of this issue's "Notices" section for more details.

Price changes go into effect the first of August, 1992. Orders received before then, including early renewals for subscriptions to expire later and multiple-year renewals, will be accepted at the old prices. This is EMI's first price rise in its seven full years of existence, and hopefully it will be sufficient for another good long while. The size of the increase has been kept to a minimum by virtue of the savings to be realized from the new quarterly publication schedule. EMI's prices reflect *very conservatively* the cost of producing a journal on a specialized topic with a very small universe of potential subscribers.

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ADVERTISING POLICY: Experimental Musical Instruments is set up to survive on subscriptions rather than advertising, but will run ads which are potentially interesting or valuable to the readership. Please write for advertising rates.

Subscribers can place relevant "classified" ads of up to 40 words without charge, and they will receive a 15% discount on display ads.

SUBMISSIONS: Experimental Musical Instruments welcomes submissions of articles relating to new or unusual musical instruments. A query letter or phone call is suggested before sending articles. Include a return envelope with submissions.

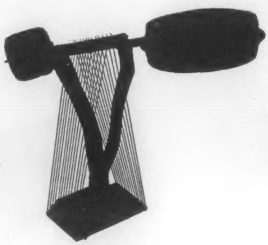
PROCESS AND DEVELOPMENT OF THE WATERHARP

By Richard Waters

After and while working on waterphone prototypes in the late sixties and early seventies I had several spin off ideas in wind, string, and percussion instruments as they pertained to water. Some of these I developed and now offer in my catalog of musical instruments and sound devices. Other water-oriented instruments were much slower to develop due to their complexity. In particular, stringed instruments are more difficult to build than most percussion or wind instruments due to alignment of the strings with bridges, resonators, and tuning pins. Another area of difficulty is keeping a tension instrument structurally sound, as the more strings it employs, the more the structure wants to bend, warp and distort. Such is the development of the waterharp and a long line of stringed water instruments that led to it.

My basic approach to instrument design is fantasy (visualization), usually coupled with simple drawings. These fantasies are tempered with what I know about the materials/tools I will be using. During the actual construction there is a lot of problem solving using visualization. I frequently have to walk away from an ongoing project just to get a little perspective. This is especially true in the tuning stages. I dislike having to cram my ideas into conventional frameworks (like design and tuning), so I don't. I am thankful when a project like this comes off successfully. Success, for me, is measured in the resulting quality of sound – timbre, range, how much the sound can be manipulated (played), and how versatile is the instrument.

It was not until I began working with stainless steel and bronze that I felt comfortable in working towards a stringed water instrument, as it gave the effort a certain longevity that I felt was worthwhile. The basic resonators for most of my water-oriented stringed instruments are constructed from two stainless bowls or pans fused together at their lips and with a holes or apertures usually at the center-top. And there were a lot of hopeless failures along the way that sounded worse than they looked, yet even these served to point the way for future efforts (what not to do). The design parameters at this point in time focused on how many playable sides the instrument would have (one side, like a guitar, or two, three, four, or in the round), and how to couple the water resonator(s) with the sound board/support so as to get maximum transference of vibrations. I ended up building a two-sided waterharp with tiered string arrangements (see photos 1 and 2). I had designed and built a series of instruments that were one sided with a stainless resonator at each end. For the most part these were not satisfactory until I built the waterlyre in about 1980 (see photo 5). The waterlyre was a breakthrough for me as I was able to realize (1) detachable and interchangeable water resonators, and (2) a series of fifteen strings being looped over the bridge and back down the other side, making an additional fifteen strings available to the player both for plucking and for bending the tone of the string on the opposite side of the bridge. This made it a double-sided axe. Both of the new developments for me were useful in the design and construction of the waterharp.



I usually do not jump into a project of this size without some sort of stimulus. That didn't come along until 1988, when a keyboard player/composer came to my studio and expressed an interest in an acoustic stringed instrument with a wide range and the possibility of water sounds. She had recently had a dream that she was playing an instrument that was like an abstract spider web that gave off beautiful, strange sounds. We talked at length about stringed instruments and waterharps and general parameters like string numbers and size of the instrument. It was not until 1989 that she was able to come up with an agreed upon sum for me to build her a waterharp. And after selecting a good wide range of stainless steel, spring tempered strings and a few bronze strings, plus some hardwoods (hickory, ash and walnut) and other hardware including the resonators, I began work. I thought that since the waterlyre ideas had worked so well that I would more or less blow it up size-wise and call it good. Wrong. It didn't work out like that due to fact that the mass of wood was too heavy (large and dense) for the strings to drive the two-bowl type resonators except in a few upper partials.

It was at this point I thought I might try a medium sized (eighteen inch diameter) small single-bowl resonator mounted between the two rows of strings and right in the center of the instrument (see photos 2 and 3). Since this was an open, bell-like (two quart) storage bowl, it vibrated in sympathy to a much wider range of frequencies than did the prior resonators, which were the two-bowl fused type. This was due partially to the flexibility of a single open bowl, and partially to the manner in which the bowl was attached to the instrument (nodal points) and the proximity of the bowl to the strings.

The waterharp can be played either on its stand (which is detachable) or suspended from an overhead support. The watersounds are activated by touching or moving the waterharp so as to start the water into motion as the instrument is being played. There are frequent little water echos when the instrument is played, and this can be extended by moving the instrument in a more deliberate way. About an eighth of a cup of water is used in the single bowl resonator, and that seems about optimum. The sound of the single-bowl resonator can be modified by adding or subtracting water, but it seems that too much water makes the instrument heavy and the resulting sound sluggish, while too little water yields rather faint water sounds.

Each of the sixteen strings have three bridges (metal). They pass over and are divided into two unequal lengths, which makes for thirty-two tones, not counting the water sounds or other tones achievable by bending the strings. And,

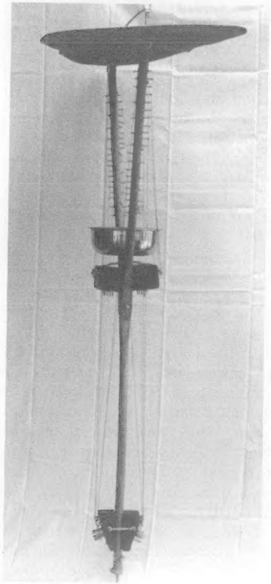


Photo 1

LEFT: Photo 1. Edge view of the Waterharp (excluding detachable stand). At the top of the photo is the cello resonating plate. At the center is the water resonator with two tuning blocks below and two more at the base of the foot. The bass strings run top to bottom. 6 feet high.

RIGHT: Photo 2. A closer view of the Waterharp showing the diagonal and horizontal string arrangement, water resonator and two tuning blocks. Note the tension bar above cello resonator.

BELOW LEFT: Photo 3. Close-up of the water resonator and individual bridges and tuning pins and blocks. Note string angles. The bass strings are to the outside.

BELOW RIGHT: Photo 4. Close-up of the foot or base showing the detachable stand. These two walnut tuning blocks hold the bass string tuning pins. The clamp is for reinforcing the hickory harp bottom where a stainless steel pin is inserted from the stand. This is what allows the harp to stand upright when it is not being suspended from an overhead support.

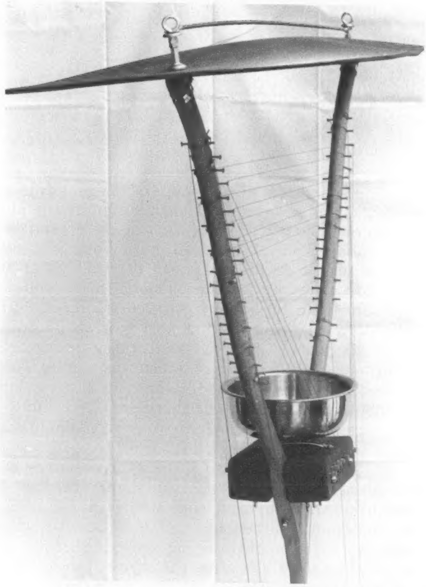
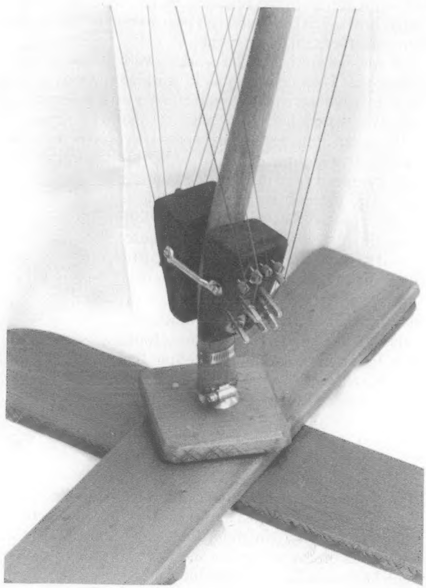


Photo 2

Photo 3

Photo 4



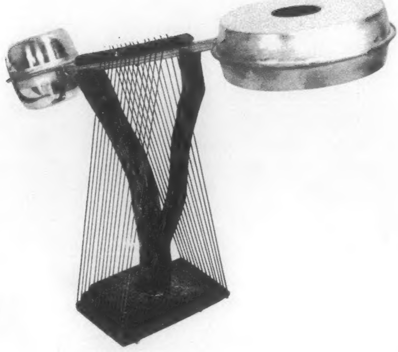


Photo 5. Waterlyre.

as I wanted to have a good bass range, I routed ten of the largest strings down to the base or foot to another tuning block with pins (see photos 1 and 4). This was done to give these ten bass strings a long length, and it also distributes the stress load more evenly, which is important in tension-type instruments. To further amplify these bass sounds, I bolted a cello back to the top of the hickory fork to act as a resonating plate. The cello plate was bolted with two eye bolts through which a quarter inch bronze bar was bolted for additional sympathetic resonance and structural support. The overhead cello resonator did not use water.

After the construction was finished, I tuned the strings against resonators and against each other. That is, starting on the low end, I would tune a bass string until I heard a harmonic response from the open bowl or the overhead cello resonator, and then I would tune the next string so that it would not be dissonant to the first, and so on. The strings at the higher end were tuned microtonally, whereas those in the lower end had larger intervals. The variable here was the bridges and double string sections, as tones could be bent so some pitches that were not sympathetic to the resonators or water sounds could be made sympathetic by bending the pitch.

After building the waterharp I thought additional technique might be needed for playing this instrument, so I made/collected a series of Bamboo sticks, guitar picks and mallets that I used. My final act with the waterharp was to talk about it and play it while making a sound recording and then shoot a roll of black and white 35mm film. I called my patron and she came and picked it up the next day.

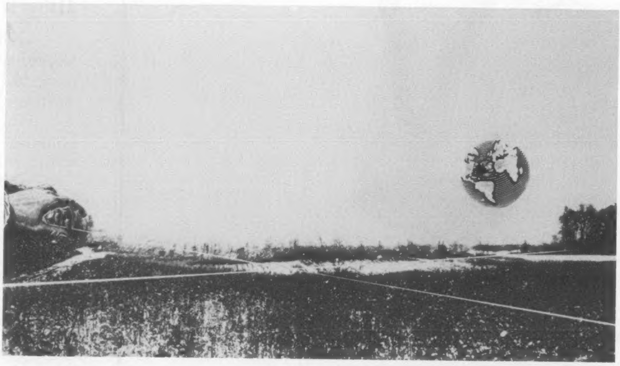
ASPECTS OF THE TERRAIN INSTRUMENTS

By Leif Brush

Leif Brush creates systems for listening to the sounds of natural events. Sometimes the sounds and events he monitors are large in scale, like the internal cracking of huge ice floes. Sometimes they are minuscule, like the fall of raindrops upon leaves, or insect movements. Sometimes he seeks to capture natural sounds in their purest forms, like the sounds of changing internal stresses within the wood of trees – and sometimes he listens to sounds of natural forces in interaction with elements of his installations, like the wind acting upon long wires that he has strung up. Sometimes the sounds are presented exactly as they come in, and sometimes Brush manipulates them electronically at the receiving end for aesthetic or exploratory purposes.

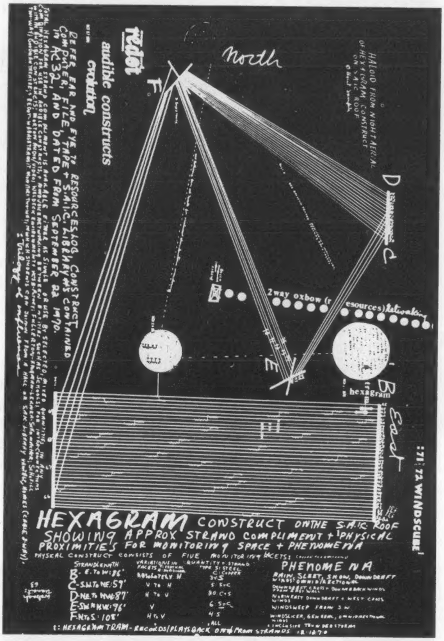
He uses sensors in the form of contact mics (of various specialized types) attached directly to wood, wire, ice or whatever, to convert internal vibrations within the materials to electrical signals, which can then be monitored or recorded using equipment at the site of the installation. He also often sends the signal, by wire, radio, or satellite transmission, to distant places, allowing people removed from the original environment to hear them in another context.

Brush made his first experiments in natural sound monitoring in 1968. He began a series of site-specific monitoring installations called Terrain Instruments *in the mid-seventies. In the years since, the* Terrain Instruments *have grown increasingly sophisticated, and have continued to form the central focus of his work.*



Above: FIGURE 1

Below: FIGURE 2



My early professional accomplishments with sound relied on the air microphone, which I abandoned after 1964. From that time forward, I have coupled specific selective, non-airborne sensors to DC amplifiers for the purpose of overhearing physical nature's vibrational sources. I use FM radio transmitters to carry individual preamplified vibrations from galvanized and stainless steel and plastic fishing line strands of varying gauges and lengths, very often over one hundred feet. The transmitted signals derive from a wide range of sound sources involving atmospheric phenomena acting upon these man-made materials.

A nine gauge strand is the largest I have used; it served mainly as a wind monitor. By using upgraded sensors along with flat rather than round wire, I eventually achieved results which, to me, seemed less a monitoring by wire and instead a mirroring of the wind. Although the resulting sounds are related, in principle, to other "stringed instruments," my perception is that the quality of the sound does not appear to be coming from a man-made wire. From 1975 onwards this 1/2 inch, two hundred foot long *Terrain Instrument: Brass Ribbon* has been my source for listening to the wind. My work, then, has striven to transcend "man-made" connotations through use of selected electronics and materials.

I left commercial radio broadcasting in 1960. At the School of

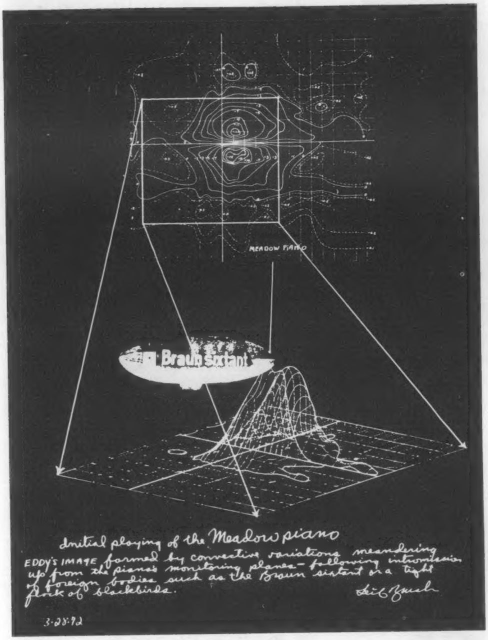
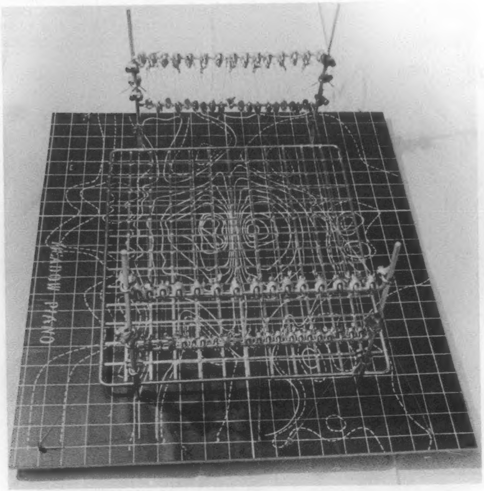


FIGURE 3

FIGURE 4



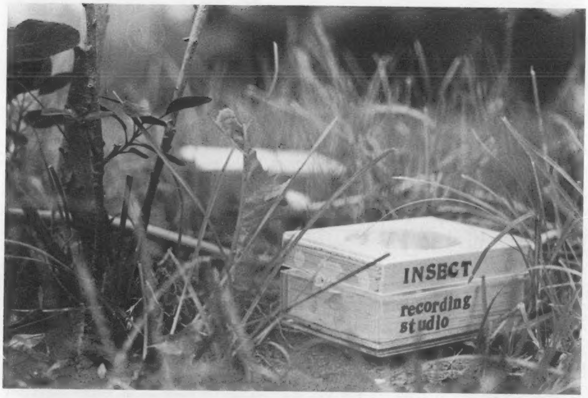
the Art Institute of Chicago (1964-72), I focused upon atmospheric sound phenomena. In 1970 I initiated a sound course, Audible Constructs, and later left SAIC with an M.F.A. in sound sculpture. I had developed a concept of the satellite as a potential "conductor" and new medium for artists hovering above the world, and I began prototypical *Terrain Instruments* in support of this idea. I think that natural sounds should be directly available globally from their sources without any packaging, and be transmittable to the home via prompting from the telephone's keypad. My *Permanent Forest Terrain Instrument* has contributed to this concept of global sources and world playing. Although synthesized libraries are widely available and clearly the popular choice for "sound tracks," the demand for natural sound sources could well expand.

Figure 1: **Major snowflake listening and recording project** accomplished in 1967-71. Above this dormant Michigan strawberry field, two galvanized wires, one 1/16th of a mile long and 22 gauge, and the other 1/4 mile long and 16 gauge, were secured to opposing trees at a height of approximately twenty feet above ground, via anchors and turnbuckles. The resulting tapes led to experiments with computer sampling (in the days of cards). I learned that the type, speed and angle of a snowflake striking the wire contributed to a unique signature, which could be used as a switch: nature could "play" nature (on/off, the type of signal and combination selection, etc). The sounds were transmitted over landlines and created analog images which were recorded in Illinois on a facsimile machine. Ranging from sensing snowflakes to hearing shifting and bouncing winds and down drafts from Lake Michigan, this overlapping work involved a semi-permanent wind-listening installation. The addition of the collaged globe and hand to the photograph signifies my interest in satellite communication.

Figure 2: **An installation at the School of the Art Institute of Chicago** made in 1972. As the diagram shows, 16 and 22 gauge galvanized steel strands were installed on the roof of the School building. At the N. and E. points, guyed towers were used to gain height and a vertical plane. The triangle construction was used mainly to intercept wind; the rectangle on the E. end was a deliberate attempt to capture a simultaneous plane of rain drops. Both ends were turnbuckled to 4X6s, which were attached to wall ends. Through this, I discovered that both vertical and horizontal monitoring planes could be used to influence and duplicate sound planes (e.g., using frontwards to backwards switching) in an interior playback situation using multiple speakers. The wind could be imaged spatially. Temperature variations affecting the strands could be translated in sound on the order of an aural thermometer. (The aspect of the weather forecast spoken as "38 degrees, F or C" now has a parallel universal tone.)

Figures 3 and 4: **Meadow Piano**, an installation proposed in 1972 (but not actually built). In the **Meadow Piano**, all phenomena occurring from a foot below ground level to about seventy-five feet above were to be available in either audible and/or visual form. This work caused me to consider the issues of audience, permanency, and interactivity. In a later work, the **Terrain Instrument: Windscube**, I carried further the work of seeing the wind, proposing a 50X50' cube housing stacked identical sensing modules: temp, wind speed/presence/direction, infrared sensors, free fall rain, snow, humidity, spectral sensors, pressure; over 50 million signal sources were to be available for interpretation through sound and/or imaging manifestations. In a related proposal, **Terrain Instrument: Iowa Riverharps** (originally published in Numus West, Mercer Island, Washington, 1975), I investigated multidisciplinary approaches in a project spanning the Iowa River, incorporating 28 microcomputer-controlled, solar-powered Trams which traversed the wires and permitted interactivity.

The graphics and captions for figures 1 through 5 are excerpted from YONY, a publication of the School of the Art Institute, Chicago, Oct., 1974. All photographs are by Gloria DeFilipps Brush unless otherwise noted.



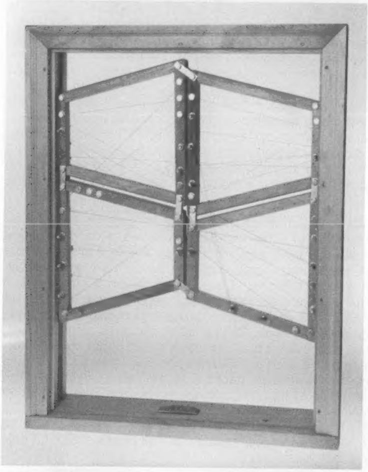


Figure 5: **Insect Recording Studio**, a system for monitoring insect activities. A linear path of sugar was laid down at the entrance and exit to induce a reliable stream of insect participants. If my Terrain Instruments are earth instruments, then the insect series had to do with scale and the details of the earthbound as counterpart to atmospheric phenomena.

Figure 6: In the 1974-75 **Terrain Instrument: Chord Draft Monitor**, I thought in practical, ad hoc terms, using lumberyard window frame, four tennis racquet holders, and Super String Co. sensors. My interest in the different aspects of wind again emerged, with updated revisions tied to FM transmitters for direct receipt by Hi Fi.

Figure 7: **Forest Terrain Instrument: Edge Playing**, an instrument for sensing internal tree sounds at the Duluth, Minnesota forest edge. Sensing the birch or evergreen required surgically clean steel probes connected to pre-amps. The probes were placed into selected areas of the tree. Sounds of twigs, branches and leaves of both species could be correlated easily with their appearance at the instant they were sounding during a gusty breeze. This was less true with sounds derived from the trunk, which was a more visually stable element. White glass rods were installed in the soil nearby for the purpose of listening to root sounds. With vibrational sensors attached, the glass rods in the earth could trace the near-surface birch roots. These sounds were added electronically to the overall collection.

Figure 8: **Terrain Instrument: Meany Ice Floe**. On the northeastern shore of Lake Superior, Perkin-Elmer hydrophones were frozen in place, their survival dependent upon their heavy rubber shielding and placement near the surface. Other sensors were crushed and lost. Galvanized steel strands of 22, 18 and 16 gauges formed a triangle. Columbia accelerometers (vibration sensors) were attached to each turnbuckle/wire; their outputs were fed to FM transmitters. On shore, receivers and a mixer collated the incoming sounds. These consisted of snow crystals striking the wires, water sloshing below, the large scale mass of ice under strain, and the concussive (horizontal lightning) sounds of cracking.

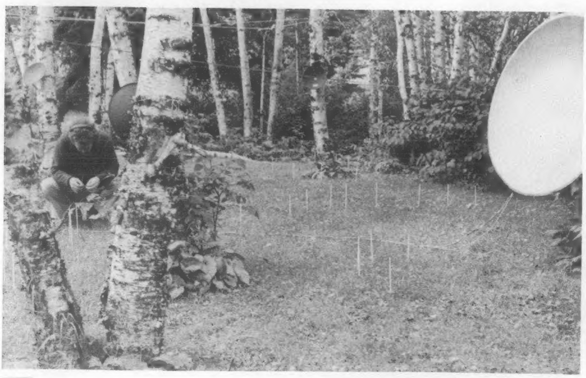
Figures 9 and front cover photo: **Terrain Instrument: Treeharps Networking**. While the tree alone produces a variety of sound qualities, I nevertheless worked them in as "players." Here, various sizes and lengths of wire and other materials were attached to sounding boards.

Above: FIGURE 5

Left: FIGURE 6

Below left: FIGURE 7

Below right: FIGURE 8
Photo by John Meany



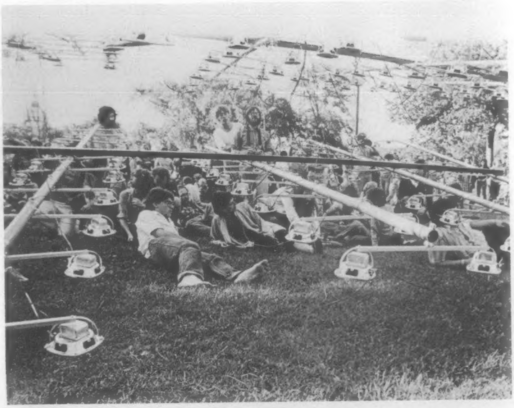
Phenomena intercepted by the strands had their pitches altered by tree movements. I found that with the tree fully sensed and equipped with solar and battery backup, it was constantly available as a composite sound source for monitoring and/or self-broadcasting.

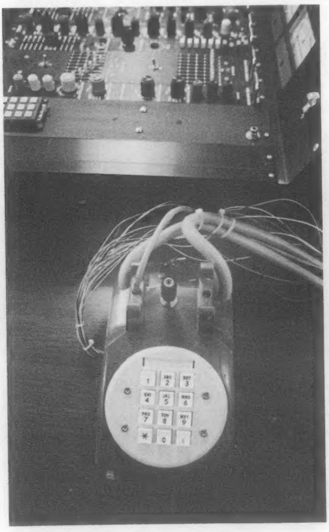
Figures 10 and 11: **Terraplane Chorography II: International Listening** (1980, New Music America, Walker Art Center, Loring Park, Minneapolis) and **The Telephone Finally Earns Its Keep** (Minneapolis Institute of Arts, 1989). Through the **Terrain Instruments**, I had achieved one of my goals, that of finding additional natural vibrations to parallel a 200-piece orchestra. Having done so, it became necessary to seek the aid of the microcomputer. With the addition of 200 speakers and with keyboard commands, the incoming sounds could be configured variously. The **International Listening** series included five different satellite works carrying the raw sounds to each of these sites. The sites include Minneapolis, Minnesota (Walker Art Center, for New Music America 1980); Yonkers, New York (Hudson River Museum, 1982); Stevens Point, Wisconsin and Washington, D.C. (University of Wisconsin-Stevens Point and Academy of Sciences Auditorium, for New Music America 1983); Hartford, Connecticut (Real Art Ways, for New Music America 1984); and Minneapolis, Minnesota (Walker Art Center 1984.) In 1984, in a New Music America work at Real Art Ways in Hartford, before this series was completed, I was able to demonstrate that the telephone could be used to do more than simply turn on the **Terrain Instrument**. In particular, multiplexing and demultiplexing techniques were suggested. In Duluth all the sounds were mixed down to a pair and transmitted to the uplink in St. Paul, Minnesota. This audio pair was then downlinked in Hartford, and fed by equalized, 15 kilohertz landlines to the installation. Demultiplexing was accomplished. The two channel sounds were directed into their spatial context via the 200 speakers.

Figure 12: **Terrain Instrument: TeleSuonoQuad**, with collaborator Eleanor Hovda. The aluminum tubes, cabling, solar/DC powered FM receivers and amps, and the suspended mike stands comprise this satellite sound source, doubling as a recording/playback studio. FM transmitters in the nearby Duluth forest environment send their various channels to matching Sony ear receivers, where each is directed to a single line amplifier and begins sounding in an individual speaker, a group of which define the cube. Individual pots adjust each speaker's volume to accomplish the desired spatiality. The procedure for re-recording on a four channel recorder: each track is laid down and may be played back on each of the five different cubic planes.

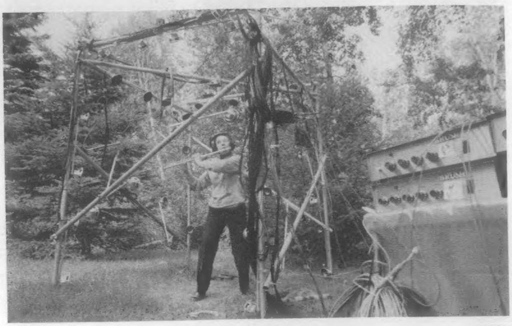
Above: FIGURE 9.
Photo by Gary Morrison

Below: FIGURE 10





Left:
FIGURE 11



Right:
FIGURE 12

FIGURE 13

Figure 13: **Terrain Instrument: Connecting Surface Waves; The Roadside Broadcasts**. In this series, **Terrain Instruments** have been placed at approximately half mile intervals zig zagging across roads. Transmissions aimed at the road from these fixed positions are maintained on the same FM frequency while a car passes between them. Their staggered spacing minimizes drift and fading from one transmitter to the next. The parabolic dish receives the whoosh from a passing car. This sound is mixed with the collected sounds from the environment (a stream) and simultaneously transmitted. A 1987 New Music America work in Philadelphia's Fairmount Park suggested that future installations must be installed in out-of-reach places, such as trees, to discourage theft and vandalism.

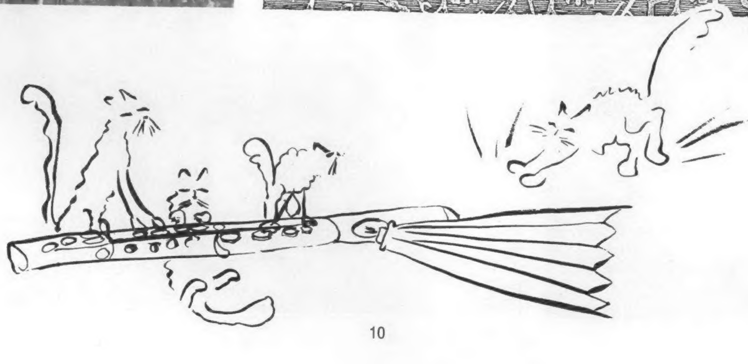
FIGURE 14

Figure 14: **Terrain Instruments: Modified Signal Disc** (magnesium, 1950s computer storage medium). This instrument has additions below and above the wooden sounding board. Its purpose is to listen to rain filtered by the tree canopy overhead. Ten rain-caused sound varieties are obtained by Shadow (brandname) sensors.

The conceptual stance for my current work involves a stand-alone system consisting of solar powered electronics with battery back up, which would be near any sound source site. This ground facility is capable of multiplexing any or all sound sources, and simultaneously transmitting two channels; one carries the composite sounds, and the other identifies menus via computer-to-telephone translator codes directly to a satellite transponder. When requested, a source-to-home route would be established to the nearest, overhead Direct Broadcast Satellite. In the home, a familiar user would go to the phone and lift the receiver and enter eleven predetermined keys. One digit renders your phone an active one so that you can be plugged into the system; a second ascertains which global menu you seek, and enters the answer; a third accesses the requested menu and the computer voice ascertains your choice of the available sources. The machine speaks the list, which is keyboard compatible. You enter your responses; one digit sets up the signal path from the originating country's satellite on through transmission to your nearest Direct Broadcast Satellite; another digit denotes a specific geographic region and also triggers a computer voice which gives operational parameters such as sources, on/off, fade in/out, volume, close up of a particular sound. Ultimately, you receive what you want in sound. Participants would require access to world sound menus and a demultiplex box. Eventual options could include a color, 3D video adaptor for simultaneously seeing the sounds.

Various aspects of the evolution of my work have been accomplished through assistance from the National Endowment for the Arts, the Minnesota State Arts Board, the Bush, McKnight and Jerome Foundations, and the University of Minnesota Graduate School.

Leif Brush can be reached c/o University of Minnesota, Art Dept. #H-317, Duluth, MN 55812, USA.

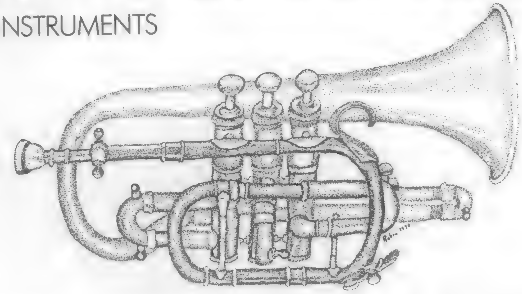


AIR COLUMN SHAPES FOR WIND INSTRUMENTS

BASIC PRINCIPLES

Part II

by Bart Hopkin



This is the second half of the article on wind instrument bore shapes that opened in EMI's last issue. While the first part used broad strokes to convey (I hope) a generalized understanding of air column acoustics, we will do a little more nitty gritty work here. There will be more detail to keep track of, or perhaps get lost in, but for people interested in wind instrument design and construction, it is a practical sort of detail.

This article is part of a series dealing with practical wind instrument acoustics. Still to come is a study of toneholes: their function, design, placement and sizing, along with practical tips on making them.

Part I of this article concluded with a discussion of the acoustic properties of the three most common and musically useful bore shapes – in theory, at least – for wind instruments: cylindrical with one end stopped, cylindrical with both ends open, and conical. As I indicated then, these three bore shapes are ideals rarely adhered to in actual practice. Let us now refine a bit our picture of how such air columns function, and then look at some of the ways that existing instruments deviate from the ideal.

REFINING THE PICTURE

End Corrections; Frequency & Wavelength Calculations

The earlier discussion proceeded as if the pressure node/displacement antinode (that defining point of maximum air movement for a standing wave in a wind instrument air column) appears exactly at the open end of a wind instrument tube. This is a simplification. Actually the standing wave extends a bit beyond the opening. The amount of the resulting increase in effective tube length depends on the diameter of the open end. It also varies with frequency, being greater for higher frequencies. For practical purposes this *end correction factor*, which we'll label with the italic l, can be approximated in a simplified fashion as $l \cong 0.3d$, where d is the tube opening diameter. This is reasonably accurate through much of the musical range, becoming less so at higher frequencies.

As an example: a tube of actual length L = 100 cm and diameter d = 5 cm, open at both ends, will have an effective length of $L + l + l$ (the end correction factor l is applied twice . . . once for each open end.) This works out to an effective length of 103cm. Since the open tube encloses half the wavelength (as we saw in the first half of this article), this gives us a full wavelength of 206cm. I happen to have on my wall a chart that EMI published in February 1989 (Vol. IV #5), relating wavelengths to frequencies and sounding pitches. This chart tells me that a wavelength of 206 cm corresponds to a pitch near G# below middle C. Assuming no other offsetting factors are present, that G# should be the sounding pitch of our 1 meter tube's fundamental resonance.

Had I not had the chart on the wall I could have calculated the frequency using the formula $f = c/\lambda$, where λ is the wavelength, and c is the speed of sound (343.5 m/sec is an acceptable value for c at room temperature). [For easy reference, all these formulas appear again in an appendix at the end of this article.]

It is important to note here that musical instruments will not always produce the pitch this sort of calculation would predict. In practice, other factors come into play. Most conspicuously, the reed, edge tone, or whatever else is providing the initial impulse can pull the pitch up or down substantially. The rigidity of the tubing material as well as whatever is forming a stopped end also affect the sounding pitch, as less rigid materials will lower the resonance frequencies of a tube of given dimensions.

I stated a moment ago that the end correction factor is not actually constant for a tube of given dimensions (as the above approximation implies), but increases for higher frequencies. This leads to another important result: Because the higher frequency waves tend to overreach the pipe end more than their lower brethren, the upper registers in wind instruments tend by nature to sound flat. Those higher frequencies "see" a longer effective tube length than the lower. We will discuss later some of the ways that instrument makers deal with this problem.

Effects of Air Column Thickness, Cross Sectional Shape, and Bends

Short, fat air columns are generally poorer in overtones than long skinny ones. This is partly because the end correction effect is exaggerated with the large opening, throwing the higher harmonics far enough out of tune to prevent their getting involved in the predominant regime of oscillation. And it's partly because the large opening, as we shall see later, does not do a good job of reflecting high frequency waves back into the pipe, with the result once again that high ongoing frequency oscillations aren't as readily stimulated as lower ones. We can see these considerations in practice in the ranks of a large organ: the thickest pipes are the flute pipes, which are characterized by lots of fundamental and little presence of overtones. The string pipes, which are much more slender, show prominent harmonic overtones. In the extreme cases, excessively fat pipes won't speak at all, and excessively slender ones tend to break up into harmonics rather than produce the fundamental.

These considerations take on additional importance in connection with single pipes designed to produce multiple pitches (which includes most air column wind instruments

other than organs). Every time you open a tone hole, slides a slide or opens a valve, you change the length/diameter ratio for the instrument in hand. This affects tone, and may be a limiting factor on range at one end or the other.

Is there an ideal L/d ratio one can strive for? The author of a homemade flute making book has suggested a standard ratio of about 23 to 1 for his flutes ranging from 16" to 23" (Mark Shepard in **Make a Flute!**). But as the organ ranks example above indicates, people will select different ratios as they seek out different tone qualities.

A related question is: how can you best retain the same general tone quality in pipes of different lengths? For instance, how can you retain a similar tone quality throughout a rank of organ pipes, or in all the instruments of a wind instrument family such as soprano, alto, tenor and bass recorders? The obvious answer would be to retain the same L/d ratio across the range. This would, in fact, help ensure that the overtone components of each pipe would be about the same relative to its fundamental. It turns out, though, that the ear hears the lower pitched pipes in such an arrangement as relatively dark, and the higher ones as relatively bright. To create greater unity of timbre, the lower pipes should be a bit longer relative to diameter, making for a slightly richer harmonic spectrum. The desired result is that the general tessitura of overtones (so to speak) does not vary so drastically across the range. A rule of thumb developed by organ builders over the years has been to increase diameter by about 2/3 for a pipe that is twice as long and intended to sound an octave lower.

This might be a good time, as we are discussing organ pipes, to point out an interesting consideration. The tubes of most woodwinds and brass instruments must be capable of producing many tones. This puts considerable restrictions on the forms they can take, as we have seen. Organ pipes on the other hand need only produce one tone each. They can be custom-designed for that pitch. This gives organ pipe designers a great deal more freedom; they can provide pipes with calculated irregularities set to enhance specific harmonics of the given tone. An example of this is chimney pipes, which have smaller tuned columns connected to the main air column, designed to resonate certain pitches within the overall overtone blend.

The cross sectional shape of an air column has little acoustic consequence. Instead, cross sectional *area* is the important consideration. This may be confusing in light of our frequent use of the terms conical and cylindrical. An air column which is square in cross section, and of uniform dimensions over its entire length, behaves the same as a cylindrical pipe of the same cross sectional area. A straight-sided square pipe which increases in cross sectional area at a uniform rate behaves like a conical pipe.

It's also generally assumed that as long as cross sectional area retains the intended value, it doesn't matter how the tube may curve and snake around — a cylindrical pipe will still behave acoustically like a cylindrical pipe even after bending, as long as in the process no kinks are added to break up the cross sectional shape anywhere. This convenient assumption actually isn't quite true. In the region of the pipe's curvature, there is an effect that is functionally similar to a tiny increase in diameter, which can alter the sounding pitch, albeit very slightly. Sharp bends, in addition, can cause wave reflections within the air column that may interfere with the desired pattern of oscillation. This phenomenon has its most pronounced effect on the way notes begin, as it affects the vibrating behavior of the air in the tube in those first moments when the predominant regime of oscillation is being set up. In general, however, bent tube effects are relatively minor and manageable, as the abundance of bends in the tubes of successful wind instruments everywhere suggests.

Drawings these pages and next: Cornet (conical bore with flared bell); Persian double reed (cylindrical bore with unflared bell); and sopranino recorder (reverse conical bore).

Drawings by Robin Goodfellow.

Effects of Different Materials Used for Air Resonators

Resonances within a given air chamber, regardless of shape, are influenced by the rigidity of the walls. Wall texture or porosity make a difference as well.

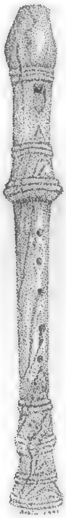
Most wind instruments are made with round tubes. The circular cross section shape is good for rigidity, whatever the material. As a result, the differences in resonance characteristics between round tubes of standard materials are quite small. Tests have shown that most metal tubing materials are virtually indistinguishable in this regard, given identical dimensions. But regardless of the material, when tube walls are extremely thin and light, as with some silver flutes, vibrating tube walls become a significant acoustic factor. Such wall vibration does not appear to contribute much to sound radiation, but it can absorb energy and damp internal resonances. The natural bull kelp tubes that have been discussed in this journal as wind instrument tubes, which are very light and somewhat flexible, show very noticeable damping effects. Likewise, the flat walls of square tubes, being structurally less rigid, are likely to add noticeable amounts of damping if they are thin. Walls made of porous materials also have damping effects.

In general, despite a lot of traditional lore about which materials are best for wind instruments, any reasonably hard, smooth and rigid material will sound very much like any other such, and have as good a chance of producing a good instrument. It should be noted, though, that extremely hard reflective materials aren't necessarily the ideal: people often prefer the mellower tone of somewhat damped resonances.

BELLS AND MOUTHPIECES

Radiation and reflection at tube openings

In part I of this article we discussed how soundwaves reaching the opening at the end of a tube are partially reflected back into the tube, and partially allowed to cross into the open air to propagate from there. We now need to look



more closely at what takes place at this critical juncture.

A key factor in the manner in which sound waves travelling in a tube react when they arrive at the tube opening is the relationship of the wavelength to the size of the opening. The bigger the opening relative to the wave length, the greater is the percentage of wave's energy to pass through the opening and propagate into the air. As a general rule, any wavelength of less than about twice the size of the opening will not reflect at all; all its energy will radiate into the open air. For longer, lower frequency wavelengths, correspondingly larger amounts reflect and smaller amounts radiate. The amounts of reflection at different frequencies affects the functioning and sound of the instrument in major ways, but the relationships involved are seemingly contradictory. One might expect frequencies which radiate very strongly to be the loudest from the point of view of someone in the room, but in fact they're generally not. Without adequate reflection back into the tube, no resonances at these frequencies are set up. They never develop any power; in short, they're not where the action is. Frequencies which reflect more are likely to be the most powerful, since they easily set up and perpetuate strong resonances in the tube. The strength of these resonances more than makes up for their less efficient radiation.

The diameter of the opening is thus quite significant. Large openings are efficient radiators, especially at high frequencies, but as a result they don't do as well at reflecting and setting up strong resonances in the tube. Saxophones, for instance, which have very large openings at the end of the tube as well as very large tone holes, do not set up strong resonances at high harmonics. But the lower frequencies, whose longer wavelengths reflect well at the openings, set up strong resonances. With the large openings they radiate from, they're quite loud. Oboes, by contrast, have small tone holes and a small end-opening which do better at reflecting and setting up tube resonances for high frequencies; this again is reflected in the tone. But the overall volume is restricted by the limited capacity for radiation of the small openings.

Let us now add another factor into the equation. For cylindrical instruments, and conical instruments of very narrow bore and angle, it is possible to increase the size of the opening, and thus increase radiation efficiency, by adding a flaring bell. Furthermore, if the rate of curvature is right (such a bell should curve outward; it shouldn't simply be a straight-sided funnel), the bell shape can still help reflect high frequencies back into the horn, so that the increased radiation efficiency of the larger opening area is not purchased entirely at the expense of the higher resonances. Thus trumpets, with their relatively narrow tubes and outwardly curving bells, tend to be both loud and bright. Cornets, on the other hand, don't have much of a bell – like saxes, their conical bore means that the main tube is quite large by the time it reaches its end point and the flare at that point doesn't add much. Cornets as a result have good volume, but are mellower in sound, with less pronounced high frequency resonances.

On woodwinds, open toneholes can also have the effect of increasing radiation efficiency by, in effect, creating a larger cumulative opening and thus more radiating surface area. This is because the sound in a woodwind may radiate out through not just the first, but the first several open toneholes. The small bells found on many woodwinds are designed to provide a comparable amount of total opening area for the lowest few notes down the tube, for which there are few or no open toneholes to help radiate the sound. Without the bell, the lowest notes would have noticeably less available radiating area, and their timbre and volume would be noticeably different as a result.

Bells and open tonehole rows greatly improve the sound of the instruments they grace, as any performance on a bell-less plumbing-pipe bugle will demonstrate. But they have the disadvantage of effectively increasing the size of the open end and thus increasing the detuning of the upper modes, which due to their higher frequencies have larger open end correction factors. As we shall see later, wind instrument makers have learned to compensate somewhat for this by altering bore shape elsewhere in the tube.

With all this talk about radiation vs. reflection, it is interesting to compare what happens within a wind instrument tube to what can be heard outside. In general, wind instrument bells and tone holes tend to radiate high frequencies very much preferentially, since their diameters are small relative to longer wavelengths. A probe microphone inserted into a sounding tube will reveal a far darker, duller sound than what we hear outside.

Effects of Mouthpieces and Reeds on Air Column Resonances

Let us move in our discussion from the far to the near end of the tube. The effects of mouthpieces and reeds on the air column resonances stem from two factors: their contributions to overall bore shape and volume, and the effects of the relative softness of reeds and lips.

The yieldingness of either lips or reed brings the tube's resonance frequency down slightly, relative to what it would be were there a rigid barrier in the same location. Wind players deliberately control the elasticity here, by tensing the lips more or less, or by clamping teeth and lips down on the reed more or less firmly, as a way of controlling the lips or reed's natural vibrating frequency. This produces the predictable effects: tighter lips or more rigidly-controlled reed raise slightly the resonant frequency of the tube. The effect is more pronounced at higher frequencies. This stiffening is one of the ways that players compensate for the natural flatness of the upper registers in most winds.

Reeds or lips may also contribute to the sounding frequency by virtue of their own preferred pulsing frequency (the frequency they would pulse at were they not connected to an air column). The reed or lip frequency preference can draw the actual sounding frequency of the coupled system (reed plus tube) up or down. The player can control this, once again, by stiffening the reed or lip. Players also commonly contribute to the effect by varying oral cavity resonance, bringing the tongue up in the mouth. These techniques are used (often unconsciously) for fine intonational adjustment during performance throughout the range, and especially for bringing the upper registers up to pitch. For brass in particular, they also serve to select which register or air column

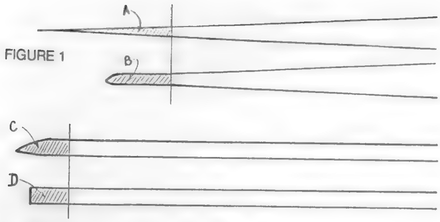


FIGURE 1: EQUIVALENT VOLUMES. For most conical wind instruments, the need for a mouthpiece at what would otherwise be the apex of the cone makes it impossible to have a true cone. You can achieve a fair approximation to the acoustic behavior of a true cone if the volume of air enclosed in the non-conical region created by the mouthpiece (region B above) is roughly equivalent to the volume that would have been enclosed in the missing apex portion of the cone (region A above). In cylindrical tubes, the effective column length of a non-cylindrical mouthpiece (region C above) approximately corresponds to that of a cylinder containing the same volume (region D).

resonance will actually sound.

When we consider the shape of the mouthpiece as part of the overall air column shape, it begins to become apparent how far removed most wind instrument shapes are from the cylindrical or conical ideals. This is especially conspicuous for supposedly conical instruments: where the apex of the cone should be, we have a definitely un-conelike arrangement, particularly odd and complex in the case of brass mouthpieces. It turns out that one can get a handle on the situation – albeit a somewhat simplified one – by thinking in terms of equivalent volumes. If the mouthpiece encloses the same total volume of air that the cut-off portion of the cone would have, then the overall air column will show resonance peaks at frequencies close to those that the complete cone would have, so that the desired tunings will be roughly preserved. The effects of an imperfect missing apex volume match can be fairly pronounced, leading to serious mistuning in the upper frequencies.

To apply the same reasoning to cylindrical instruments, think of the length of additional cylindrical tubing that would have the same volume as the actual mouthpiece. The resonances of the overall air column will correspond roughly to the those of the basic tube with this equivalent-volume length added in place of the mouthpiece.

Remember, though, that, as described above, the elasticity of the reed or lips applied to the mouthpiece will considerably enlarge the effective mouthpiece volume to be used in finding these equivalences. Be aware, too, that these equivalent volume calculations are fairly accurate and useful at lower frequencies, and so work well for figuring fundamental sounding pitches. But at higher frequencies, where upper partials come into play, the effect of mouthpiece shape and volume on air column resonances follows a more irregular pattern.

While equivalent volumes allows rough calculations of the main air column resonances, the mouthpiece will still have its own higher frequency resonances, and the peculiarities of its shape may enhance or inhibit specific frequencies. Most notably, brass instrument mouthpieces usually have a very broad resonance peak of their own in the region of the upper overtones of the instrument's sound – around 800 - 900Hz for a trumpet mouthpiece, for instance. This strengthens these partials, and serves to brighten the overall sound considerably. Small differences in the mouthpiece cup and backbore size and shape make a big difference in overall instrument sound.

Overall air column shape

Let us step back for a moment and consider how all the bore-shape factors we've been describing work together. We can get a handle on this by starting with an imaginary lip-buzzed instrument consisting of a simple tube (uniform cylinder, no mouthpiece or bell), and then reviewing what can be done to improve it. When someone buzzes their lips into the simple tube, it produces a nearly perfect harmonic series in its resonance peaks, offset only slightly by the frequency-dependent effects of the end correction at the small opening. It lacks volume and brilliance, as the small end does not radiate well. To give it more radiating room, we can imagine ourselves enlarging the end of the tube with a flared opening. The flare makes the instrument quite a bit louder, but it diminishes its ability so set up high frequency resonances, because high frequency waves are reflected poorly at the larger opening. It matters not that higher frequencies are more efficiently radiated; if the resonances at those frequencies aren't being set up in the tube, then there won't be much to hear in that range. We can partially offset the loss of high frequency reflection and resonance by redesigning the flare to create a bell with the right sort of curvature: we won't go into the details here, but this can affect the impedance change at the bell so as to help reflect more of the highs back into the horn. The large, opening does, however, also contribute to a greater degree of flattening in the upper registers by augmenting the frequency-dependant effects of the open end correction factor. We can further boost the highs by using a mouthpiece having a cup with its own very broad resonance peak in the general medium high frequency range we want to enhance. Now we have an instrument little like a valveless trumpet. It is most certainly no longer a simple cylindrical tube. We still have the problem, though, that the higher resonances are badly out of tune due to the flaring opening and its end correction. Not only are the upper registers seriously flat, but the brightness of tone we hoped for is diminished by the fact that we're not getting good cooperation between modes – happy, healthy regimes of oscillation are not being set up as the poorly tuned upper partials aren't fully able to take part.

Register tuning problems like this, stemming primarily but not exclusively from open end factors, are a serious consideration in sophisticated wind instrument design. Over the centuries, makers have learned to deal with them (with varying degrees of success) through further manipulation of the tube shape. With this in mind, let us look at the effects of irregularities occurring along the length of a nominally conical or cylindrical tube.

At any point where a tube thickens, the air within, being less confined, will lose some of its springiness, or, to be clearer, will act like a softer spring of lesser stiffness, as compared to the more restricted air in narrower portions of the tube. Air in narrow points in a tube will conversely act stiffer. The effect that this will have on a standing wave in the tube depends upon where along the wave the constriction or bulge occurs: 1) If a *bulge* happens at or near a point of maximum pressure variation (pressure antinode/displacement node) it lowers the frequency of the wave as a whole, just as a softer spring would vibrate more slowly. If the bulge happens at or near a point of maximum air movement (displacement antinode/pressure node) it will increase frequency for the wave as a whole,

FIGURE 2A

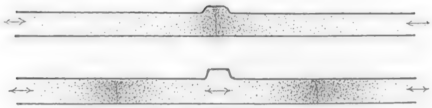
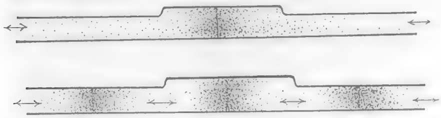


FIGURE 2B



FIGURES 2A and 2B: PERTURBATIONS IN BORE SHAPE.
Small perturbations such as that shown in Figure 2A tend to be fairly specific in their effects. In the upper drawing, a small bulge appears directly over a region of maximum pressure variation for the fundamental in an open tube. It will lower the frequency of the fundamental in an amount proportional to the volume of the bulge. The lower drawing shows the same bulge in relation to the open tube's second mode of vibration. For this mode, the bulge falls directly over a region of maximum air movement. The effect will be to raise the frequency for this mode. Thus, the same perturbation, by virtue of its placement, can have specific and sometimes opposite effects on different modes.

Figure 2B shows a longer bulge in an otherwise similar tube. The upper diagram shows the longer bulge still falling primarily over the region of maximum pressure variation for the fundamental mode, and thus lowering its pitch, just as in Figure 2A. The lower drawing shows the effect of the same bulge on the tube's third mode. Here the bulge affects a much larger portion of the wavelength, including both regions of maximum pressure variation and maximum movement. This produces opposite effects which tend to cancel, with the result that sounding pitch is scarcely altered. The lesson to be drawn here is that while short perturbations may, depending on their location, have noticeable effects on all but the shortest wavelengths, longer perturbations are likely to have pronounced pitch effects only on the longer wavelengths associated with lower modes, and less impact on the shorter wavelengths of upper modes.

FIGURE 3

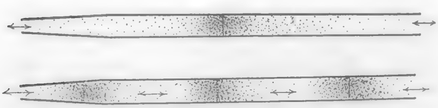


FIGURE 3: TAPERING TOWARD THE MOUTHPIECE END OF A FLUTE, AND ITS EFFECTS ON DIFFERENT MODES.
The upper drawing, representing the flute tube's fundamental mode of vibration, shows that the slight taper near the blowing end of a flute causes constriction in an area of maximum movement, lowering the sounding pitch for this mode. The lower drawing, representing the flute's third mode, shows the same taper again covering a region of maximum movement. But for this mode its effect is partially offset by the fact that there is also some constriction – albeit, a bit less – over a region of maximum pressure variation. Thus, while the first mode is substantially flattened by the taper, the third is flattened somewhat less. It turns out that the flattening effect of the taper continues to diminish as one moves to higher modes and higher pitches. This is just what is needed to offset the increasing upper mode flatness that would characterize the untapered tube.

because in effect the movement will be less inhibited. 2) For localized *constrictions*, the reverse is true.

The same effects arise from irregularities in the rigidity of the tube walls: a section with more yielding walls is effectively the same as a bulge.

For a bulge or constriction of given length, the greater the volume the greater the effect. However, if the length of the bulge or constriction is short relative to the wavelength, it generally has greater effect than one which is spread out over the better part of a wavelength or more. The reason is that the longer bulge is likely to include regions of both positive and negative pressure variation for the vibrational mode question, and the effects will tend to average out. It follows that localized perturbations tend to have greater effect on longer wavelengths/lower modes than on shorter/higher, as can be seen in Figures 2A and B. Also, highly localized perturbations are likely to have effects which vary quite a bit from one sounding pitch to the next, since their impact falls at different places relative to the nodes and antinodes of different wavelengths. The effects of longer perturbations are more gradually distributed through the range.

The important thing to notice here is that the effects of localized perturbations in the bore shape are wavelength-specific. One can, by clever placement of a bulge or constriction relative to the relevant nodes & antinodes, affect the tuning of different tube resonances differently, or of one resonance and not another. This can be used in initial instrument design, or it can be used to fine tune an existing instrument. In particular, it can be used to lower the lower registers of wind instruments, with lesser effects on the upper registers, to compensate for the usual flatness in the upper registers.

Simple flutes will serve as a good practical example. For several centuries now, flute makers have compensated for the natural upper register flatness by creating a slight taper toward the blowhole end. An effective taper might be a gradual reduction in tube diameter starting at a point about 1/5 of the total tube length from the mouthpiece end and reaching a total reduction of about 10% by the time it gets to the stopper just beyond the blowhole (see Figure 3). The constriction thus created is at its maximum near the blowhole, which is a displacement antinode for all the flute modes. The taper should accordingly lower all modes. But the length of the taper is such that its effect will be spread out over a broader part of the shorter wavelengths of the second and third registers. This mitigates its impact on those modes. In general, the higher the pitch, the less the detuning effect of the taper. Meanwhile, for the longer first register standing waves, the taper has its impact concentrated where it most matters, and so these lower tones will be most affected. In short, the taper selectively lowers the lowest tones the most, and in doing so brings the whole instrument more in tune.

Different sorts of variations in air column shape are used to correct overtone tuning in other instruments. In brass, for instance, the common configuration has the narrow back bore of the mouthpiece leading to a gradually expanding section of tube, followed by a long middle section that is cylindrical or at least expands more slowly, followed by the more rapid flare leading up to the bell (Figure 4). This particular combination of elements has traditionally been thought of as compensating for the various irregularities introduced by the bell and mouthpiece, to create in total a well-tuned tube. In fact, the brass story turns out to be more complex, and really quite fascinating. Without ever having the mathematical tools to analyze what they were doing, brass instrument makers over the years

FIGURE 4

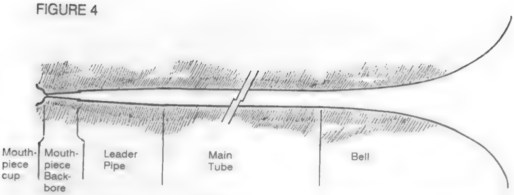


FIGURE 4: BORE SHAPE FOR A TRUMPET-LIKE BRASS INSTRUMENT. This sort of bore is commonly described to as cylindrical, but clearly the shape is a bit more complex than a simple cylinder.

have arrived by trial and error at a configuration which is not what it appears or has been assumed to be, but which works amazingly well. The series of resonances available on standard western brass instruments, corresponding to the pitches that can be produced by different lip tensions with a given fingering, *would seem* to comprise a well-tuned harmonic overtone series starting for some reason not with the first, but the second harmonic. But acousticians now suggest that they actually represent a series of slightly detuned selected overtones from a different fundamental, which itself does not sound effectively due to lack of support from its displaced partials.

Air column perturbation effects arise in other connections too, such as the space created by slightly pulling out a mouthpiece or barrel joint to tune a woodwind, or the effect of the row of little side cavities along the tube associated with a series of closed toneholes. In these situations the peculiar shapes of the cavities don't matter much except in so far as they effect the length of the bulge relative to wavelength. More significant is the volume of air enclosed. With cylindrical tubes, the percent frequency change resulting from any irregularity in air column shape will not exceed the percent change in overall air column volume resulting from the irregularity. Conical tubes are more sensitive to irregularities.

We should mention here one other practical consideration in air column shape. The most common form of flutes, the side blown flutes, have their blow hole in the side of the tube, while the tube itself extends a bit beyond the end of this hole to terminate at a stopper a short distance away. The blow hole is normally thought of as one of the open ends, even though it's not actually located at the end of the column. At the same time, the stopper forces a displacement node at its location. This very much effects the shape of the standing wave, especially in light of its need to have a displacement antinode at the blowhole; and so the optimal placement of the stopper makes a big difference in the flute's effectiveness. The standing wave does not behave as if the node were located precisely at the stopper, but a point somewhere beyond it which varies with the frequency of the wave in question, as well as the distance from the player's lips to the edge. A compromise stopper position is thus in order (one which produces reasonably acceptable results over a range of frequencies). Remaining discrepancies can be compensated by the player with lip position (a subtle technique, but flute players are used to it; they do it all the time). It's a good idea to make the stopper position adjustable, and then find the best position through trial and error. A good starting position is about 2/3 of the tube diameter from the center of the blowhole.

HELMHOLTZ RESONATORS

Thus far we have been speaking about air columns. Enclosed bodies of air which are not columnar, but fully three dimensional, may also possess well-defined resonance peaks and so can also serve for wind instruments. The best known globular flutes in the west are ocarinas; the jug band's wine jugs would qualify as well; the egg-shaped Chinese hsun is another form; and there are many others from around the world and across the years. In addition, tuned globular resonating chambers are important in many bass marimbas; and similar chambers, less deliberately tuned but important in their tuning none the less, play essential roles in the bodies of guitars, violins, conga drums and countless other instruments.

The 19th century physicist Hermann von Helmholtz studied such resonating systems extensively, and they have come to be known as Helmholtz resonators. Helmholtz chose a particular shape of chamber for his experiments, but the term has since come to be more widely applied. A general definition of Helmholtz resonator might go something like this: a Helmholtz resonator is an enclosed body of air, open to the air outside through a restricted opening, in a form that is not so long and thin as to resemble an air column, but reasonably extensive in at least two dimensions.

The principles governing resonance in Helmholtz resonators are entirely different from those at play in air columns. The significant factor is not waves traveling from one end of the resonator to the other and the time it takes them to do so. Helmholtz resonators behave as simple spring and mass systems. The enclosed air serves as the spring, and the air being pushed around as a result of the vibratory movement, its attendant frictional resistances, represents the mass. If extra air is somehow momentarily pushed into the chamber at the aperture, air pressure within the chamber is increased, and air will naturally be pushed back out. Momentum carries the air bit too far, which causes relatively low pressure in the chamber; the movement is reversed as air is sucked back in; and the oscillation is thus perpetuated. Notice that there is no mechanism here to set up overtones, harmonic or otherwise. This is a central feature of Helmholtz resonators: they resonate at a single frequency only; the tone contains no partials, and as wind instruments they can't be made to produce anything analogous to an upper register.

Three factors affect the frequency of the oscillation. First is the total volume of the chamber, which determines the springiness of the air within the chamber. The greater the volume of air, the less stiff, in effect, will be the spring which perpetuates the oscillation; thus a larger chamber, other things being equal, leads to lower frequency. The second factor is the size of the opening. A smaller opening inhibits the air from moving freely in and out; this is analogous to increasing mass in the spring and mass system. Thus smaller aperture, other things being equal, makes for lower frequency. The third factor is the depth of the aperture; that is, the tallness of the hole or the length of the neck through which the air has to flow in and out of the chamber. Making the hole taller has the same effect as making it smaller: it inhibits the passage of air, and so lowers frequency.

So one way to alter the resonances in a Helmholtz resonator is by varying the aperture size, making it smaller to lower the pitch. You reach the lower limit in range when the hole becomes so small that there's not enough open surface area to move much air, and as a result there's not enough

volume. The upper limit is reached when the aperture becomes so large that the springy effect becomes too diffuse, the resonance frequencies lose their definition, and the thing simply doesn't oscillate very well. While you can theoretically make a small, yet low-pitched Helmholtz resonator simply by having a very small aperture size, such an instrument would be ineffective in terms of volume. Yet you can do pretty well in creating a low-frequency resonator with a surprisingly small chamber. The tone, being all fundamental with no upper partials, tends to have a satisfyingly bassy sound. A globular ocarina of about six inches in diameter reaches well down into the bass clef with modest but acceptable volume. This is why Helmholtz resonators rather than tube resonators are usually used with bass marimbas: where the resonator tubes for the lowest notes may need to be 8 or 10 feet long, a much more manageable Helmholtz resonator of, say, 2' X 2' X 6", tuned by means of an appropriately-sized aperture, might do the same job quite nicely.

While there are many possible means for increasing aperture size, the most convenient for ocarinas and such is simply to use tone holes that can be covered and uncovered with the fingers, as with air columns. But notice that tone holes in globular resonators function acoustically somewhat differently from those in air columns tubes. All that toneholes in globular chambers do is contribute to a cumulative total of open area. Lifting a finger to open a tonehole simply increases the cumulative aperture size, thus raising the frequency. Hole placement, as a result, is of relatively little significance except in so far as it relates to ease of playability. Hole size is the significant factor.

SUMMARY OF IMPORTANT FORMULAS AND RELATIONSHIPS

Following here are the most important or useful practical rules for air column behavior that have been discussed in this article. The symbols used for variables are defined below.

Frequency as a function of wavelength:

$$f = v/\lambda$$

End correction factor (approximate; becomes less accurate at high frequencies):

$$l \cong .3\,d$$

Wavelength and frequency for vibrational mode n in a cylindrical tube open at both ends:

$$\lambda \cong 2(L + 2l)/n$$
$$f_n \cong nv / 2(L + 2l)$$

Wavelength and frequency for vibrational mode n in a conical tube:

$$\lambda_n \cong 2(L + l)/n$$
$$f_n \cong nv / 2(L + l)$$

Wavelength for vibrational mode n in a cylindrical tube closed at one end:

$$\lambda_n \cong 4(L + l)/(2n - 1)$$
$$f_n \cong (2n - 1)v / 4(L + l)$$

Conical tubes and cylindrical tubes open at both ends ideally produce a complete overtone series.

Cylindrical tubes closed at one end ideally produce an overtone series having only its odd-numbered components.

Air columns having large d/L ratios tend to be poor in upper harmonics. Air columns having small d/L ratios tend to be rich in upper harmonics.

An increase in tube diameter or an area with less rigid tube walls occurring over a pressure antinode for a given mode tends to lower the frequency for that mode, while a bulge or less rigid walls over a displacement antinode tends to raise frequency. The reverse is true for constrictions or regions with more rigid walls.

Larger tube openings (toneholes or tube ends) tend to increase overall volume but weaken upper partials.

NOTATION CONVENTIONS FOR EQUATIONS

These conventions are arbitrary, but they are widely used in physics texts.

λ = Wavelength (the symbol is the character **lambda** from the Greek alphabet).

f = Frequency.

v = Velocity, used here to indicate the speed of sound. The actual speed of sound varies depending on atmospheric conditions, but a good average figure for normal room temperature is 343.5 meters per second. The letter c is sometimes used in place of v in this application.

L = Length (used here for tube length).

l = End Correction (the additional length that must be added to actual tube length to find its effective air column length)

d = Diameter (used here for tube diameter).

n = Used here to indicate vibrational mode number (e.g., for the first mode of vibration for a given body of air $n = 1$; for the second $n = 2$; etc.). Thus f_n represents the frequency for mode number n.

ACKNOWLEDGEMENTS

Sincere thanks to Professor Donald Hall for his knowledgeable and insightful criticism of the manuscript for this article.

BIBLIOGRAPHY

Two basic sources were used extensively in the preparation of this article, both of them excellent general texts on musical acoustics. They were 1) Donald Hall's **Musical Acoustics: An Introduction** – designed as a college level textbook, and accessible, lucid and practical throughout – and 2) Arthur Benade's **Fundamentals of Musical Acoustics**, another enlightening, if more demanding and at times idiosyncratic, overview of the topic. A fuller bibliographical listing follows.

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BUILDING A COLOR ORGAN

The Harmonicophone Shows Notes and Harmonics Sounded

By Manuel Comulada, Instructor of Acoustics, Army Music School, Washington, D.C.

Originally published in **Science and Invention**, June 1922.

This is the fourth in a series of reprints currently appearing in EMI featuring early 20th century popular magazine articles devoted to unusual musical instruments. The current article, first published in 1922, describes a system for closing electrical circuits selectively in response to different sounding frequencies, by means of a set of Helmholtz resonators. The author's idea is that the system can be used purely for aesthetic pleasure, as a color organ (activating differently-colored lights in response to different frequencies), or as a rough sort of spectrum analyzer, with glowing lights indicating frequencies present (following an approach first applied by Hermann Helmholtz). Spellings and punctuation in this reprint are as in the original.

For a full history of color organs, see Ken Peacock's articles in EMI Volume VII, #2 and 3.

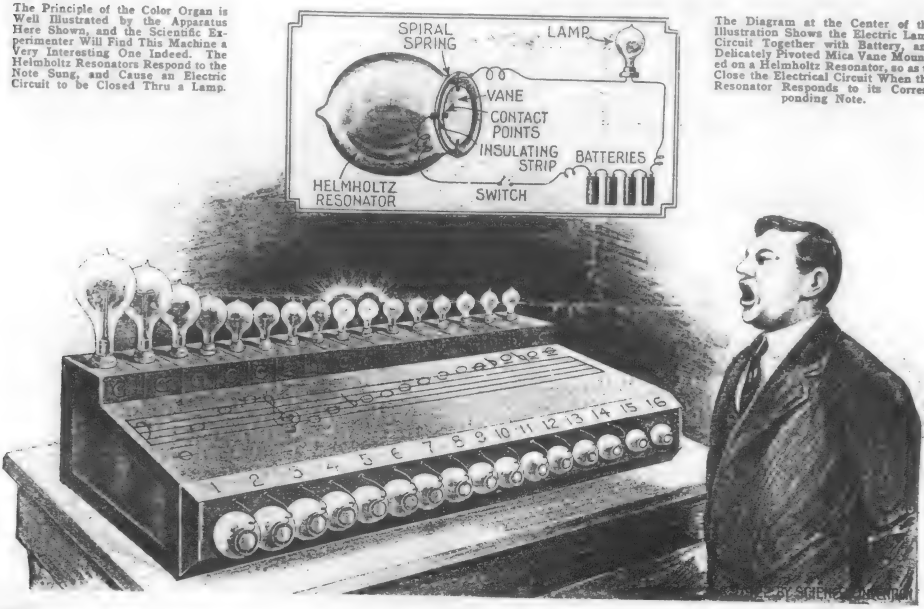
Nearly all musical sounds are composites of a series of higher partials or overtones, which are superposed on the fundamental sound produced by blowing a pipe like that of a flute, clarinet or trombone, as well as sounds of strings excited by friction like the violin, or by striking as is the case with piano strings.

The position, number and relative intensities of these partials present with every musical sound causes the various tone qualities of musical instruments. The flute when softly played, has very few of these partials present, hence the suavity of tone of its lower register. Again, when very high sounds are produced in the upper register of this instrument, there are practically none of these partials present, giving us sounds very much the same as to tone color or quality.

On the other hand, if we blow an oboe, altho of the same pitch as the flute, its sounds are very rich and of a decided and distinct tone color, due to the great number and relative intensities of its partials or overtones.

With the clarinet, we have effects due to its cylindrical body (hyperbolic cylinder) connected with an elastic beating reed; the odd numbered partials of the harmonic series are far stronger than the even numbered, hence the peculiar sound given by this instrument, characteristic of the sounds produced by pipes stopped at one end.

Many musicians who are serious enough to study the science of acoustics, know the above facts in regard to musical



The Principle of the Color Organ is Well Illustrated by the Apparatus Here Shown, and the Scientific Experimenter Will Find This Machine a Very Interesting One Indeed. The Helmholtz Resonators Respond to the Note Sung, and Cause an Electric Circuit to be Closed Thru a Lamp.

The Diagram at the Center of the Illustration Shows the Electric Lamp Circuit Together with Battery, and Delicately Pivoted Mica Vane Mounted on a Helmholtz Resonator, so as to Close the Electrical Circuit When the Resonator Responds to its Corresponding Note.

instruments, but are unable to know how many of these partials are present, and what their position in the gamut of the harmonic series of each individual instrument, to account for its tone color.

By means of an apparatus like the Harmonicophone, we should be able to solve this very same problem. A saxophone player wishes to know how many overtones or partials he produces with a particular sound and tone color; the instrument is blown directly in front of the Harmonicophone, which is tuned to correspond with the period of vibration of the fundamental sound of each musical instrument under test; the fundamental as well as the overtones present are received by the diaframs whose natural periods correspond or synchronize with the rate of vibration produced by each of the simple sounds present.

By selecting a standard scale set of Helmholtz resonators, the device can be employed as a home-type color organ, the lamps being colored different for each note. As the different notes are sung or played, the corresponding lamps flash up.

A complete set of Helmholtz resonators are secured to a board or other suitable rack in the form of an instrument. Each of these Helmholtz resonators has a vane fitted across its mouth between two pivot points or bearings. This vane is further fitted with a spiral hair spring so that the position normally occupied by the vane is at right angles to the opening in the resonator. At one edge of the vane, a small silver or platinum contact point is rigidly secured and mounted on a piece of insulating material; adjusted so that it can touch this contact is another piece of silver.

In Helmholtz resonators there is a tendency for a vane placed across the mouth to assume a position parallel with the opening, or in other words, to close that opening whenever the resonator is excited. This same principle is made use of in one of the very latest designs of electro-dynamic submarine-torpedoes controlled acoustically, which device is described in the April issue of this journal, page 1152, U.S. patent No. 1,390,768.

When the flute, violin or other instrument is played, each individual or fundamental note will effect the attuned resonator and the vane in the mouth of the resonator will close, forming a circuit between the two points on the vane and insulating stand, thus lighting the lamps connect in series with the points. Of course, for each particular musical instrument, a different harmonicophone would have to be constructed to synchronize with the sounds produced, and it is advisable to secure several sets of resonators, shaving a tiny bit off the duplicate set and a little more off the triplicate set, which makes for a greater possibility of locating the harmonics and overtones and registering these accurately. The instrument is merely in its suggestive stage and altho experiments have been conducted with the same, the complete scale chart has not been calculated or experimented upon.

Scientific experimenters will be interested in this machine, not only as a color organ or harmonicophone, but also from the viewpoint of everyday physics, for the principle of this sound actuated relay, which is moreover selective, in that it responds only to the note to which the resonator is tuned, will be found useful in many branches of the electrical and mechanical arts. It would pay those interested in this whole affair, and particularly in its operating principle, to procure a copy of the patent cited above, which describes an electro-dynamic submarine-torpedo controlled by sound.

ROCKS IN RUT

By Robin Goodfellow

There are many types of instrument makers in this world, some more peculiar than others. This article deals with two of the more esoteric makers and their instruments. Unlike most instruments from makers from this century, however, some of the instruments described below are easily available to residents near the Pacific coast from Washington to Mexico.

This instrument maker grew up, as a child, with one eye, one shell and three pairs of legs. In spite of these strange afflictions, the infant grew well and developed three eyes, two shells and six pairs of legs. It still didn't settle down to its life work building pan pipes until well into its dotage, when, blind, with its head stuck in one place and feeding with its curled, feathery legs, it finally got on with serious production.[1]

Experimental Musical Instruments readers may actually encounter these mini pan pipes in collections in coastal regions of this, our own planet. The workmanship is uneven, and not all of the instruments play well. Also, they are, like the pipes of very large organs, sometimes nearly inaccessible. We are talking about *Balanus glandula*, an acorn barnacle residing on rocky coasts from Alaska to Mexico. As an adult, this sea creature, related to crabs and shrimps, lays down a secretion of cement which builds up into a volcano-shaped limy shell. When the original inhabitant dies and leaves the cone empty, this is a playable instrument. Find it at the mid to high water zone where it attaches itself to algae covered rocks or pilings.

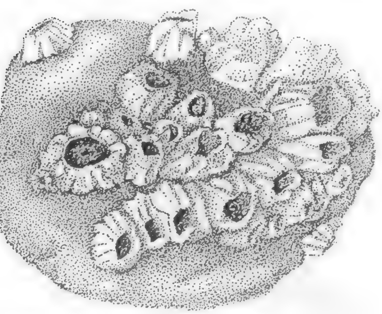
Expect a very high, piercing tone from the larger, deeper cones. Play these instruments by placing the edge of your lower lip against the edge of the hole. Blow with a relaxed, pursed embouchure, directing the air against the opposite edge as in the playing of any flute-type instrument.

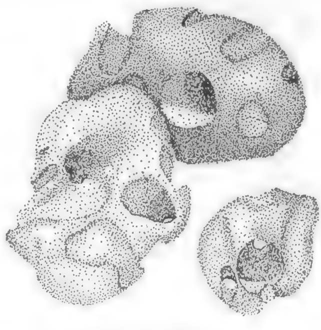
While *Balanus glandula* is busy building its pile of cement into an instrument, a more common and accessible animal, *Penitella penita* is taking existing rocks and boring holes into them for pan pipes of greater range and prettier tones. The first animal is a builder, and helps in the colonization of bare rocks. The latter is a borer and eventually destroys its own environment bit by bit. Whole rocky cliffs may someday topple into the ocean as a result of many little clams boring in closer and closer to each other in their frantic demand for more housing space.

The larvae of the *Penitella penita* swim around the ocean until they are big and strong enough to find a likely rock and begin to scrape at it. They grow a foot with which to hold on to the rock, then grow teeth to do the scraping. They scrape around and around in circles, boring more and more deeply. They scrape, then rest while growing into the shape of the holes just made, then scrape again. This could take years! If a *Penitella penita* can keep scraping and growing , it will do so, but eventually, it will probably run into some other *Penitella penita's* hole, which would be disastrous for both of them. It almost never happens, however, because these little animals know when they are about to run into each other and stop just before.

How do they sense each others presence? It has been suggested[2] that they feel the vibrations of each other's scraping. However, since they will stop before an **empty** tunnel, then, perhaps, (my own hypothesis) they "hear" the thickness of the wall much as we might thump a wall to determine if it is solid or hollow behind. This is an unusual way to construct pitch differences in an instrument, but this is what *Penitella penita* does. If another tube is near, it may twist its own tunnel around to avoid it. If other tubes prevent this , it will stop growing and working altogether on the tube, its home, its life work, throw it all over and devote the rest of its life to the pleasures of sex. Immature, adolescent *Penitella penitas* , if stopped in their growth for some reason, will enter into sexuality very quickly and are called stenomorphs[3] by non-judgmental scientists. What the other *Penitella penita* think of this has not yet been recorded.

While working on its tube, *Penitella penita* has a large foot and keeps growing teeth to scrape with, set after set as needed. When one tool wears out it grows a replacement. (This is





This page, left: The acorn barnacle, Balanus glandula.
This page above and facing page: Penitella penita.
Drawings by Robin Goodfellow.

handy when one is surrounded by the instrument being made with no opportunity to run out to the hardware store for replacements.) Then it stops working, it looses its foot and stops making cutting tools. Becoming sexually active, it decides for itself whether to be male or female for the moment, according to the availability of the opposite sex. (Life as *Penitella penita* may be boring, but it has a lot of advantages.) It sends male or female gametes out into the water to meet their opposites, play around for a while in the ocean and then settle down again to make pan pipes for the adventurous beach comber.

The holes encountered in rocks on the beach made by *Penitella penita* have been long vacated by their occupants, replaced by other visiting home seekers and used as nurseries for baby *Penitella penitas* all the while being eroded by the action of the tides. By the time they are cast upon the beach for musicians to find, they are frequently too shallow to be useful dwellings for sea creatures and may be happily employed in the production of shrill, loud tones with great carrying power. Play them in the same manner as *Balanus glandula*. (Piccolo players will have properly trained embouchures.)

Penitella penita and *Balanus glandula*'s instruments are not for everyone. They are not purchasable in stores. Players must search out their own instruments from sandy beaches, discarding about 90% of the more promising ones, playing the lucky finds. The tunings are not standard and the timbre piercing. They are, however, natural, free, and not in common collections of instruments.

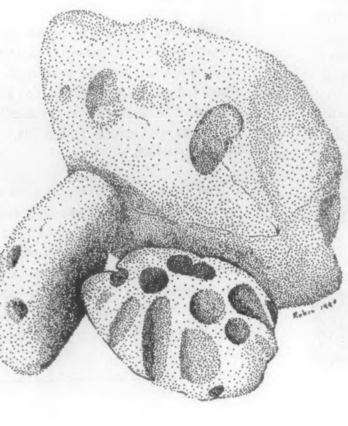
The author is indebted to Chuck Stasek, who first recognized and identified Penitella penita while I was drawing in his art class and sent me in search of the world authority. Dr. John Evans, that authority himself, very graciously sent to me the collection of his published works on the subject from St. Johns, Newfoundland.

FOOTNOTES

1. **Between Pacific Tides**, by Rickettes and Calvin, Stanford University Press, 1952.

2. "A Theoretical Consideration of Crowding and its Effects on the Biology of the Rock-Boring Clam, Penitella Penita", J.W. Evans, Ass. Prof. of Biology, Memorial University of Newfoundland, Canada; published by the 2nd International Congress on Marine Corrosion and Fouling 1968, Athens, Greece.

3. "Sexuality in the rock-boring clam Penitella penita (Conrad 1837)" by John W.Evans, **Canadian Journal of Zoology** Volume 48, Number 4 1970, published by the National Research Council of Canada.



Robin Goodfellow is a musician, graphic artist, and collector of musical instruments living in Oakland, California, where she teaches art and music.. While this is her first written contribution to EMI, her drawings have been a staple of this publication.

THE ZIL

by Liza Carbé

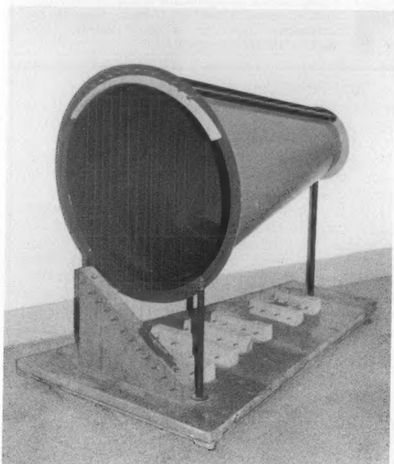
The Zil is a string instrument whose primary resonator is a three- foot long metal cone. The cone is shaped like a megaphone opening to two feet in diameter at the large end and eight inches at the smaller end. There are thirty-six strings. Twelve run across the large opening of the cone, and the other twenty-four are grouped into six sets of four running throughout the cone. The cone has three legs attached to it, two at the front end and one at the rear. These are mounted on a triangular piece of wood. The piece of wood has three functions: It provides a place to mount the cone; it acts as a secondary resonator; and it's where the tuning mechanisms are mounted.

The tuning mechanism is like that of a piano, except that each piece of wood has only four or twelve strings attached to it. The top of the cone has four metal bars running lengthwise across it. They attach to either end without laying directly on the cone. These are to support the tension of the strings and keep them in tune. At each end of the cone there is a 1/16" piece of reinforcing metal surrounding the diameter of the cone and making a 11/2" lip at the ends. The lip at the large end of the cone has the string attachments mounted to it. It also supports the bridge, which is made out of wood and lies across the uppermost part of the lip. The inner strings attach to the top of the cone by passing through the cone and supporting metal bars and then wrapping around the metal bars.

My initial idea was to play the twelve strings in front and have the inner strings act as sympathetic strings only. Although this is still the basic premise of the instrument, it is also possible to reach inside and play the inner strings or play them between the outside of the cone and where they attach to the tuners. The front strings are played in the same manner as a harp, except that you can only reach around one side of the Zil. It is also possible to bow them or use a slide (from a slide guitar), although it is primarily a plucked instrument.

It is tuned to a type of pentatonic scale which looks like this: 1, 2, *b*3, 5, *b*6. This tuning, of course, is not etched in stone, but it is harmonious with the basic timbre of the instrument, which has an East Indian sound to it.

At the moment I'm using piano or harpsichord wire for strings. It's not an extremely loud instrument and the use of metal strings give it more volume.



A node is created where the string passes through the cone and is attached to the tuning mechanism. This allows the string to have two different pitches, one on the inside of the cone, the other on the outside. It also enables you to pluck the inner string and then pull on it from the outside, to bend the sounding pitch.

NOTICES

IBM CLONE FREEWARE for JUST INTONATION. Freestanding program calculates just modulations/demodulations/intertones/complements, as well as string positions and ratio to cents. Menu driven, includes source code. Send formatted disk 51/4 or 3.5 inch, one dollar return postage (suggested) or trade material. NOVOSONICS, RFD 1 Box 312, Contoocook, NH 03329.

Pointless Music/Yucca Tree Records is seeking material for a collective CD complilation. Contributors will pay $400 to be included on the CD and will be repaid in the form of 50 copies of the CD which they can sell/distribute any way they choose. Contributors will also be repaid in the form of publicity because this project will receive a wealth of airplay, reviews, and ad space. Anyone who is interested in being considered for this project should send a cassette tape of his/her/their work to: Pointless Music, 1889 Algonquin, Kent, OH 44240.

7th ELECTROACOUSTIC SPRING sound festival, with a special focus on sound ecology, will take place in Montreal from June 6 - 21, 1992. For information: 7e Printemps electroacoustique, CP 416, succersale Outremont, Quebec, H2V 5N3, Canada; phone (514/849-1564.

Sale! SCRATCH MY BACK: A PICTORIAL HISTORY OF THE MUSICAL SAW AND HOW TO PLAY IT, by Jim "Supersaw" Leonard. Prepaid $15 per book; U.S. Dollars; includes mailing ($22.95 value). KALEIDOSCOPE PRESS, Janet E. Graebner, 28400 Pinto Dr., Conifer, CO 80433-5309.

– A new book release – THE PINK VIOLIN, compiled and edited by Jon Rose and Rainer Linz. Innovative musicians from Australia. If you are one of those people who are wondering what's it all about, where are we all going and who's paying for the pizza after the gig – you need to read this book and AND SOON. NMA Publications, PO Box 185, Brunswick, Vic 3056, Australia.

I am researching musical instruments which use a diaphragm and horn to amplify and direct the sound of stringed instruments for use in the pre-electric recording process. Info pertaining to Stroh-viols, Tiebel, Päsold-violins, James Tann 1903 USA, Joseph Rapsweg [sp?] 1928 USA and others very welcome. Gerhard Kress, 6 Maycliffe Park, Ashley Down, Bristol BS6 5JH.

Nowhere in the story of Humpty Dumpty is it stated that Humpty Dumpty was an egg.

PLATE TECHTONICS is a new cassette tape from Tom Nunn, featuring his electroacoustic percussion boards (diverse scraped, struck and bowed things on a contact-miked soundboard, with electronic processing) and space plates (metal rods on a highly reverberant balloon-mounted sheet metal resonator, played by bowing). Available for $8 plus $1 shipping & handling, from 3016 25th St., San Francisco, CA 94110.

Do you make unusual instruments for retail, or do you retail unusual instruments made by others? EMI is compiling a list/review of mail order retail outlets for unusual instruments. Send a catalog to Mike Hovancsek, 1889 Algonquin, Kent, OH 44240.

Needed for a new edition of **Directory of Suppliers**: names and addresses for suppliers of all things used by instrument makers and restorers, including tools, materials and literature. Send to Mark Norris, The Old School, Stobo, Peebles, EH45 8NU, Scotland, GB.

JEW'S HARP FESTIVAL! Sumpter, Oregon, July 31-August 2, 1992. For information contact Gordon Frazier, PO Box 14466, Seattle, WA 98114, phone 206/725-2718.

The sixth biennial SOUND SYMPOSIUM, international celebration of sound, takes place this year at St. John's, Newfoundland, July 1 - 11. For information write 81 Circular Road, St. John's, Newfoundland, Canada A1C 2Z5, or Fax 709/753-4630.

QUARTZ CRYSTAL "SINGING" BOWLS", frosted and clear in 12 sizes, in all musical notes available – magical – powerful healing tools for meditation and stress elimination, balancing energies, etc. Also available: handheld square drums, hoop and dance drums as well as water and ceramic kettle drums, various types of RAINSTICKS, melodious chimes, bells, cymbales. Largest distributor, lowest prices. The CRYSTAL STORE 1-800-833-2328.

MICROTONAL MIDI TERMINAL (vers. 1.2) by Denny Genovese lets you play nearly any MIDI synthesizer in Just Intonation! A veritable "tuning processor" as well, it has many features for constructing, editing, transposing, analyzing and printing Just Scales. Tuning data is shown in Ratios, Cents, Frequencies and Yamaha TU's. Those without a MIDI instrument can hear the Just scales on the computer's built in speaker. Holds 16 scales in memory, which are selected by single keystrokes. Tunings may be transposed into any key with another quick stroke. Requires IBM XT/AT or compatible and, for performance, an MPU-401 or compatible MIDI interface. $60 from DENNYS SOUND & LIGHT PO Box 12231 Sarasota, FL 34278.

EMI PRICE CHANGES TAKE EFFECT AUGUST 1, 1992. Order anything you want before then at the old prices. Here's the deal:

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RECENT ARTICLES, continued from back cover

The annual **Journal of the American Musical Instruments Society** Volume XVII, 1991 (414 E. Clark St., Vermillion, SD 57069-2390) has appeared. Included are articles on instruments used in the music of J.S. Bach, an obscure instrument referred to in various early European sources called the *Ruszpfeif*, **the bassoon in 17th century France, and string scaling in early Flemish keyboards, plus several book reviews.**

Percussions (18 rue Theodore-Rousseau, F-77930 Chailly-en-Bierre, France) runs a regular "Organology" column. Featured in the column in issue #20 (Feb 92) were tablas; in issue #21 (March 92) was the Swiss drum.

Glass Music World Vol 6 #1&2, Jan & Apr 1992 (2503 Logan Dr., Loveland, CO 80538) contains articles on musical glasses and glass harmonica, and a photo of Jean Claude Chapuis' glass instruments.

CAS Journal Vol 1 #8 (Series II), Nov 1991 (112 Essex Ave., Montclair, NJ 07042) contains, among others, articles on violin plate tuning, acoustic properties of spruce soundboard wood, and a "Music String Calculator" slide rule for string design.

The Soundscape Newsletter Vol I #1 (Aug 1991) and 2 (Jan 1992) (Department of Communication, Simon Fraser University, Burnaby, BC, Canada V5A 1S6) contain networking information for people interested in the sound environment, and reports on current activities of several people in the field.

The following list contains selected articles relating to unusual musical instruments which have appeared recently in other publications. Included are several older articles that did not appear in last issue's listing due to a computer failure.

"Deriving Fret Positions, Part I" by Sam Rizzetta, in **Dulcimer Player News** Vol 18 #1, Jan-March 1992 (PO Box 2164, Winchester, VA 22601).

Guidelines for 12-tone equal temperament fret placement on the Appalachian mountain dulcimer.

"Out of Thin Air" by Olivia Mattis & Robert Moog, in **Keyboard**, Feb 1992.

For more than 50 years no one in the west knew the activities or whereabouts of Leon Theremin, the Russian inventor of one of the first, and still one of the most remarkable, purely electronic instruments. Now at age 95 he's back in the public eye. This article reviews some of his activities in the interim, as well as his earlier achievements.

"Instrumentuppfinning och Ljudutforskning" (Instrument Invention and Sound Exploration) by Hal Rammel, in **Mannen PÅ Gatan** (Stockholm: Surrealistölaget, 1991).

A report on instruments designed and built by Hal Rammel, including Triolin, Aerolin, Hydro-Aerolin, Snath, Bamboo Fiddle, and Sound Pallette.

"Benade for Technicom" and "More on Fraising", both by George Jameson, in **Technicom** Vol 16 #1, Jan-Feb 1992 (National Association of Band Instrument Repair Technicians, PO Box 51, Normal, IL 61761).

In both of these articles, the author applies information from Arthur H. Benade's **Fundamentals of Musical Acoustics** to practical problems in wind instrument repair.

"Harry Partch in the Field" by Richard Kassel, in **Musicworks** 51, Autumn 1991 (1087 Queen St. West, Toronto, Ontario, Canada M6J 1H3).

The author discusses Harry Partch's work with Native American music, and its impact upon Partch's own composition.

"An African Story" by Lark Bowerman, in **Folk Harp Journal** No.75, Winter 1991 (4718 Maychelle Dr., Anaheim CA 92807-3040).

Notes on the Zairean bow harp called *kinubi*.

"A Homemade Didgeridoo" by Byron Smith, in **Connections**, Winter 1991 (Music for People, RD 4 Box 221A, Keene, NH 03431).

Instructions for making a plastic didjeridoo.

"Gongs and Gong Making in Java: Technical Achievement in the Spiritual Realm" by Philip Vandermeer, in **Percussive Notes** Vol 30 #2, Dec 1991 (PO Box 25, Lawton, OK 73502)

A report on gong manufacture in Java, with a wealth of technical information along with comments on spiritual aspects of the tradition.

"Musicmaker's Kits, Inc., Home of the Autochord" by Phyllis Barney, in **The Autoharpoholic** Vol 13 #1, Winter 1992 (PO Box 504, Brisbane, CA 94005).

Musicmaker's Kits (423 S Main, Stillwater, MN 55082) produces kits for a wide variety of traditional & folk instruments. The author describes some of the instruments, as well as some of the thinking that goes into designing for a kit.

"Folkcraft Musical Instruments" by Kieth Brintzenhoff, in **Autoharpoholic** Vol 13 #2, Spring 1992 (address above).

The author reports on a visit to Dave Marks' Folkcraft Musical Instruments, which makes a variety of folk harps, dulcimers, autoharps and the like.

Also in **Autoharpoholic** Spring '92 (address above) is a letter from Henry Lowengard describing the construction of changeable dampers for autoharps, allowing for customized chord design.

"Remko Scha (and the Machines)", Remko Scha interviewed by Frans de Waard in **H23** #3 (PO Box 2306, Athens, OH 45701-2306).

Remko Scha works primarily with electric guitars played by power saws. Here he discusses his recent work and related aesthetic questions.

"Anti-Records and Conceptual Records" by Ron Rice in **H23** #3 (address above).

A historical survey of phonograph records as an artistic medium (as opposed to records as a passive sound storage & reproduction system).

"Autosax" by Godfried-Willem Raes, in "**Logosblad** 13 #12, Dec 1991 (Kongostraat 35, 9000 Gent, Belgium).

Notes on a modified saxophone incorporating computer electronics. (In Dutch.)

"Mauricio Kagel", in **Logosblad** 14 #3, March 1992 (address above).

A report on Argentinian composer Mauricio Kagel's stay as guest composer with Stichting Logos earlier this year. Kagel is known for his compositional work with a wide variety of non-traditional sound sources. (In Dutch.)

"Building the Prima Gusli" by James H. Flynn, in **American Lutherie #27, Fall 1991 (8222 South Park Ave., Tacoma, WA 98408).**

Plans for building this Russian lap zither.

"The Portuguese Guitarra: A Modern Cittern" by Ronald Louis Fernández, also in **American Lutherie** #27 (address above).

Natural history of this cittern-like instrument. A striking feature is the instrument's unique tuning machines.

"Free Plate Tuning" by Alan Carruth, in **American Lutherie** #28, Winter 1991 (address above).

An introduction to the practice of fine-tuning the wood resonances in string instrument sound boards. This article is valuable because it brings together material that has appeared in a series of more technical articles in the **Journal of the Catgut Acoustical Society**.

"Von Huene Builds Contrabass Recorder", in **Newsletter of the American Musical Instrument Society** Vol XX #3, Oct 1991 (414 E. Clark St., Vermillion, SD 57069-2390).

A description of the making of what may be the world's largest recorder by Frederich von Huene.

Iin AMIS Newsletter Vol. XXI #1 (address above), in the "Ask AMIS" column, a discussion of free reeds in Asian mouth organs, and their manufacture.

(continued on page 23)